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# Development of an Ultrasonic Detector for Calcium Sulfate Scale Deposits

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## FOREWORD

This is one of a continuing series of reports designed to present accounts of progress in saline water conversion and the economics of its application. Such data are expected to contribute to the long-range development of economical processes applicable to low-cost demineralization of sea and other saline water.

Except for minor editing, the data herein are as contained in a report submitted by the contractor. The data and conclusions given in the report are essentially those of the contractor and are not necessarily endorsed by the Department of the Interior.

## TABLE OF CONTENTS



## LIST OF FIGURES

TABLE OF CONTENTS (Concluded)

LIST OF FIGURES (Concluded)

SUMMARY

The purpose of this program was to develop an ultrasonic method for the detection of calcium sulfate scale which may form on the inside surfaces of heat transfer tubes. This purpose has been achieved and an additional benefit--early detection of boiling (and cavitation)--has been realized.

Scale deposits as thin as 0.001 in. can be detected with relatively compact electronic equipment and a small transducer. The latter device is attached directly to one of the heat tubes.

The sensitivity of the unit is such that the heat exchange tubing at the test point must be reasonably round internally--severely eccentric tubing prevents usable results. Selected grades of commercial tubing have been found satisfactory for use and test sections of such tubing may be readily welded into desired test locations. Five such test sections have been prepared and will be submitted to OSW for use in field tests of the scale detector.

# I. INTRODUCTION

In a previous OSW program at Midwest Research Institute, various ultrasonic techniques were explored for their potential usefulness in detecting calcium sulfate scale in heat transfer tubes. The most promising technique utilized small curved transducers bonded directly to the outside surface of the tubes. Pulse echo patterns from these transducers were quite sensitive to scale deposits on the internal tube surfaces. In this follow-up program, a more detailed study of this specific technique was conducted and a unit with improved sensitivity was developed.

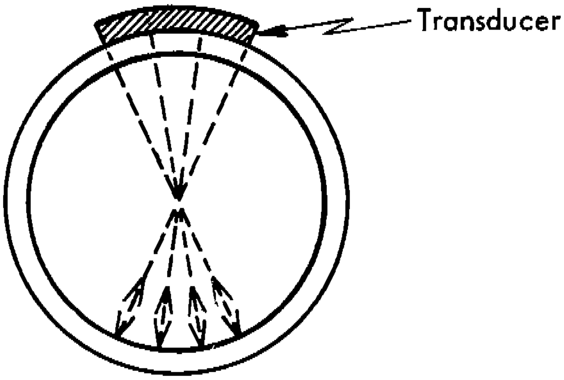
Based on the results of the earlier program, plans were made to develop techniques for applying transducers to heat transfer tubes on existent and future conversion plants so that ultrasonic results could be reproducibly correlated to scaling conditions. We have shown that instrumented test sections of tubing can be fabricated in the laboratory and the test results from these sections are very reproducible. The installation of these test sections at selected locations in full scale conversion plants should provide an early indication of scale formation.

The ultrasonic instrumentation will also give early warning of the presence of boiling.

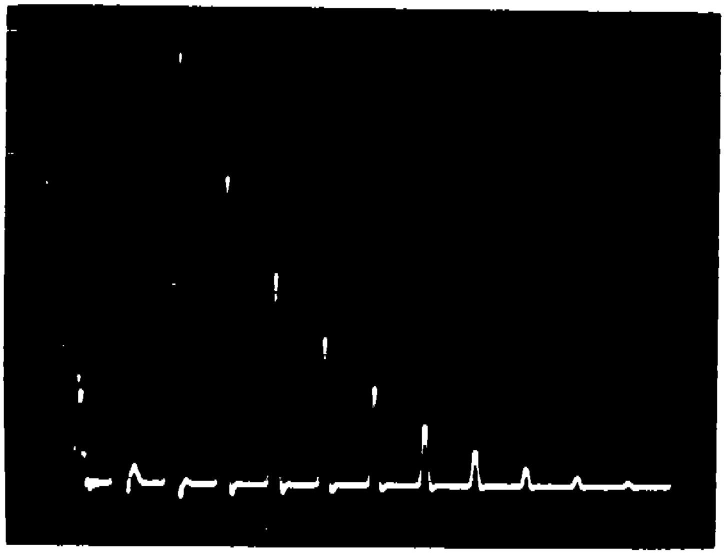
Project activity included the following areas of major emphasis: (1) investigation of methods for applying transducers and obtaining reproducible ultrasonic echo patterns, (2) design and assembly of a brine circulation and scale deposition system, and (3) evaluation of relationships between ultrasonic results, scale conditions, and other factors such as temperature, flow rate, and concentration factor of the circulating brine. Details of these activities and the ultimate results are given in the following sections along with a description of the prototype instrumentation which will be delivered to the Office of Saline Water.

# II. GENERAL DESCRIPTION OF TECHNIQUE FOR SCALE DETECTION

The ultrasonic technique which received primary attention during this program utilizes small curved transducers bonded directly to the heat transfer tube as illustrated in Figure 1a. In pipes with truly cylindrical interior surfaces, geometry of this type produces a cylindrically convergent wavefront which focuses at the center line of the tube and then diverges to impinge on the opposite tube wall at




(a)



(b)

Figure 1 - Sketch Showing Focusing Effect of Curved Transducer on Round Tube (a) and Oscillogram of Typical Pulse Echo Pattern (b)

normal incidence. The reflected wave then converges again at the center line before returning to the transducer which serves as both transmitter and receiver. This reflection process can occur many times before the ultrasonic signals are dissipated by absorption and/or scattering. When the transducer is connected to suitable electronic instrumentation an exponentially decaying pulse-echo pattern is obtained similar to that shown in Figure 1b.

The presence of calcium sulfate scale on the inside surfaces of the heat transfer tube produces an increase in the decay rate of the pulse-echo pattern. The resultant changes, even for relatively light scale deposits, are large compared with other experimental variables which affect the decay rate.

The curved transducers used in this program were cut from ceramic tubes of piezoelectric composites of lead zirconate and lead titanate. These materials have a Curie temperature of about 300°C and thus remain operative at temperatures well in excess of those encountered in flash distillation plants. Figure 2 is a photograph showing one of the "as received" ceramic tubes and several pieces which had been sectioned from a similar tube. Also shown is one transducer soldered to a section of cupro nickel tubing. The ceramic tubes were sectioned into suitable pieces using a small, diamond-impregnated, cutoff wheel.

The wall thickness of available piezoelectric tubes is generally greater than 0.050 in. Thinner walled tubes are subject to breakage during fabrication and handling. The 0.050 in. wall mentioned above corresponds to a resonant frequency of about 1.5 MHz. Although such a frequency might be satisfactory for some scale detection applications it is usually desirable to operate at a higher frequency in order to detect fairly light deposits. These higher frequencies can be obtained by driving transducers at harmonics of the fundamental resonance. This technique was used during the early phases of the program because it provided an excellent method of studying results over a significant frequency range. Reasonably good pulse echo patterns can be obtained with a 1.5 MHz transducer at odd harmonics up to the 11th or 13th. The 11th harmonic, of course, corresponds to a frequency of about 16.5 MHz.

Generally, the shorter wavelength signals, corresponding to higher frequencies, are more strongly affected by scale deposits and thus might be considered most desirable. However, other factors cause problems at the higher frequencies. Frequencies between 5 and 10 MHz provide a suitable compromise.

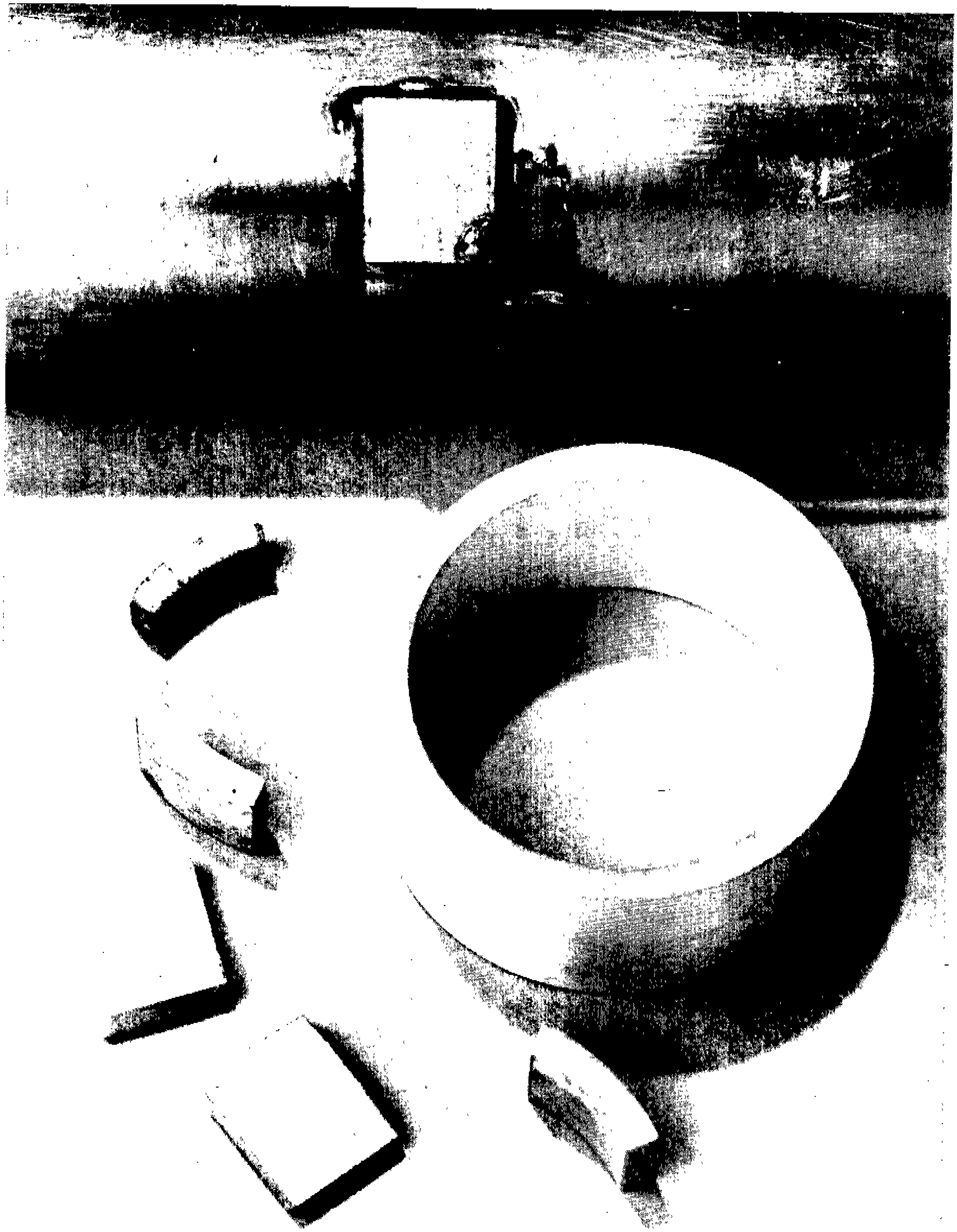


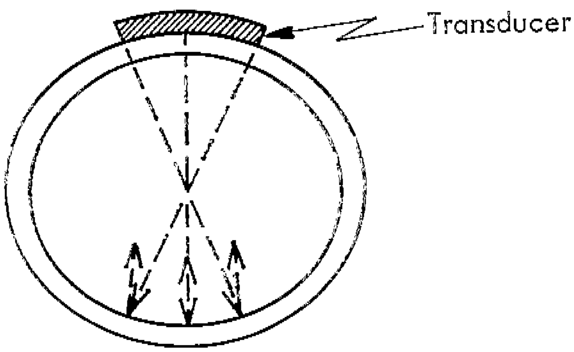
Figure 2 - Piezoelectric Ceramic Tube and Curved Transducers Cut From a Similar Tube. At the top is a section of cupro nickel tubing with a transducer soldered in place.

## III. APPLICATION OF TRANSDUCERS TO HEAT TRANSFER TUBES

The piezoelectric tubes are normally supplied by the vendor with silver electrodes applied to the internal and external cylindrical surfaces. In ordering these tubes the inside diameters are specified to be within ± 0.002 in. of the outside diameter of the heat transfer tubes to which the transducers are to be applied.

During this program, we investigated numerous solders, adhesives, and other techniques for bonding the transducers to the heat transfer tubes. The bonding problem is made more difficult by the hostile environment to which the ultimate system will be exposed. The bonding material must be a satisfactory conductor of high frequency ultrasound and remain stable under exposure to steam at temperatures near 160°C. Materials which were investigated included various solders, silicone rubbers, cyanoacrylate cements, epoxides, polyimides, and several other organic compounds. Of the materials evaluated, solder ultimately proved to be most satisfactory but even here serious difficulties were encountered. The trouble was ultimately traced to the silver electrodes which cover the inside and outside surfaces of the transducer. The inside electrode is, of course, wetted by the molten solder and then takes up the adhesive load as the solder hardens. The normal silver electrodes, usually found on commercial transducers, exhibit wide variability in that some dissolve in the molten solder and others, which successfully resist dissolution, subsequently fail by weak adhesion to the ceramic. The dissolution problem was minimized by using a solder containing 1 to 2% silver and satisfactory electrode adhesion was ultimately provided by Transducer Products, Inc., of Torrington, Connecticut.

We found that the use of this technique on standard, commercial tubing led to great difficulty in obtaining reproducible, exponential pulse-echo patterns. We first believed that this difficulty was due to subtle variations in our bonding techniques. Subsequent investigation indicated, however, that the problem was primarily related to the geometry of the heat transfer tubing. Because of eccentricity found in some tubing it is impossible to even approach the ideal conditions represented in Figure 1. In fact, even <u>slightly</u> elliptical tubing such as that illustrated in Figure 3a may produce pulse-echo patterns similar to that shown in Figure 3b. The latter oscillogram was obtained using a commercially supplied tube whose 1 in. outside diameter varied by as much as 0.010 in. The echo patterns representative of the noncylindrical tubing are quite dependent on the exact location of the transducer relative to the major and minor axis, but in general they contain fewer echos and their envelope is nonexponential.




(a)

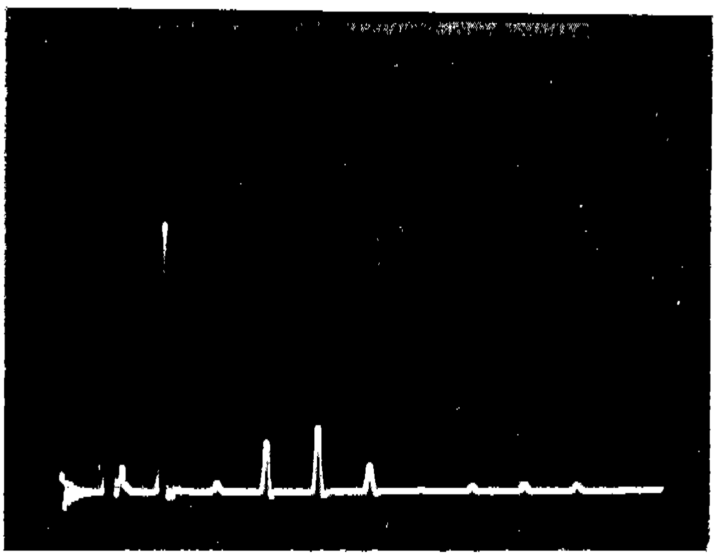


Figure 3 - Transducer on Out-of-Round Tubing (a) and Typical Nonexponential Pulse-Echo Pattern (b)

Some effort was directed toward minimizing the variability due to the above problem by carefully placing the transducers on either the major or minor axis of the noncylindrical tubes but completely satisfactory results were never achieved. Since the tubing used in this project was typical of that often used in saline water conversion plants, we concluded that it would be impossible to standardize the techniques of transducer application so that reproducible results could be achieved in the field. We further concluded that "test sections" of specially prepared or selected tubing should be instrumented in our laboratory for ultimate installation in experimental OSW plant sites.

We gratefully acknowledge the assistance of Revere Copper and Brass in supplying the special tubing.

The final procedures used in preparing the test sections were as follows. The cupro nickel tubing was first cleaned by scrubbing the surface with fine steel wool and Alconox, followed by thorough rinsing and drying. The area to which the transducer was to be applied was then slowly heated until it started to melt the solder.* The transducer was then placed onto a drop of molten solder and pressed against the tube until the solder solidified. The transducers were about 1/4 in. by 1/4 in. so enough surface was present to cause the tube and transducer curvatures to match quite well when pressure was applied.

Previous mention was made of the fact that the transducers could be driven at odd harmonics. In reality, primary excitation of a single harmonic is difficult unless the ultrasonic generator provides a tunable burst of RF voltage. Such instrumentation was available at MRI for laboratory investigations but the prototype electronics (see Section V) utilizes so-called "spike" excitation, i.e., the transducer is excited by a single short-duration voltage spike. Using this type of instrumentation the transducer may vibrate in any number of modes, but most of the expended energy will exist in the fundamental thickness mode. Under these conditions, it was desirable to use transducers with resonant frequencies of at least 6 MHz; but, as mentioned previously, large O.D. piezoelectric tubes are not available with the walls thin enough to resonate at 6 MHz. Thus, the transducer thickness was reduced to about 0.012 in. after the transducer was soldered to the heat transfer tube. This was done by mounting the cupro nickel tube in a collett on an O.D. grinder equipped with a 60-grit carborundum wheel. The grinding process removed the original external electrode, which was then replaced using an aerosol silver spray paint (E-Kote 40, Allied

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* Kestor "44" Resin Core Solder containing 1.4% silver, 62.5% tin, 35.75% lead, and 0.35% antimony.

Products Company, New Haven, Connecticut). Electrical connection to the transducer was then completed by again using E-Kote 40 to attach a flexible lead wire to the transducer electrode. A 7 ft. length of the Teflon-coated lead wire was used for each transducer to facilitate ultimate attachment to an electrical feed-through connector which will have to be installed in the chamber wall of the brine heater or evaporator stage in which the unit is to be used. The second electrical connection to the transducer is the heat transfer tube which is assumed to be at electrical ground.

After the transducer connections were completed the tubes were baked for several hours at 160°C to stabilize the silver electrode. The entire transducer area was next covered with RT-106 silicone adhesive sealant (General Electric) and after setting several hours at room temperature the units were again baked at 160°C. Test sections prepared in the above manner exhibit good stability under rough handling and exposure to high temperature steam. Several of the test sections prepared for delivery to OSW are shown in Figure 4.

Figure 4 - Photograph of Several Instrumented "Test Sections" of Cupro Nickel Tubing

## IV. BRINE CIRCULATION AND SCALE DEPOSITION SYSTEM

General details of the experimental brine circulation and scale deposition system are shown in Figure 5. This system includes several features which facilitate monitoring of the actual scale condition and it provides close simulation of the environments experienced in saline water conversion plants. The reservoir is a 10-gal. pressure cooker with the inside surface covered with FEP-PTFE coating. The reservoir is equipped with a pressure gauge PG-1 and a valve V-1 which can be used for adding either water, simulated seawater, or pressurized nitrogen to the system. The simulated seawater circulates clockwise through the system as shown passing through a flow meter and an auxiliary heat exchanger before passing into the test section where the ultrasonic transducer is located. Pressure gauge PG-2 provides information about pressure on the suction side of the pump and valve V-6 provides a bypass which facilitates control of the flow rates through the test section. Thermocouples T-1 and T-2 monitor the seawater temperature at the inlet and outlet sides of the test section. Two additional thermocouples are used to monitor the steam temperature and the external surface temperature of the heat transfer tube in the test section. Steam, supplied by a 24 kw. portable steam generator, passes into the test-section heat exchanger where the condensate is vented through steam trap (ST). A sampling loop was also built into the system but it is not shown in Figure 5. This loop, which can be valved off and cooled, facilitates the extraction of a sample of seawater for titration. The cooling is necessary to prevent the sample from flashing into steam when the temperature is above 100°C.

An important part of the circulation and deposition unit is the test section and heat exchanger, the main features of which are shown in Figure 6. A cut away section of this drawing shows the small cylindrically shaped transducer bonded directly to the heat exchange tube on the side away from the steam inlet manifold. Immediately above the transducer, a small window arrangement permitted direct viewing of the inside surface of the heat exchange tube. This window was quite valuable during initial testing in that it facilitated evaluation of actual scaling conditions. Swagelock fittings and the flange at the top facilitate removal of the test section from the rest of the system and replacement of transducers on the heat exchange tube.

Most of the circulation and deposition system is shown in Figure 7 along with some of the ultrasonic gear and other auxiliary equipment. The insulated 10 gal. reservoir is easily identified in the photograph. The brine circulation pump is partially hidden behind the box which supports the reservoir.

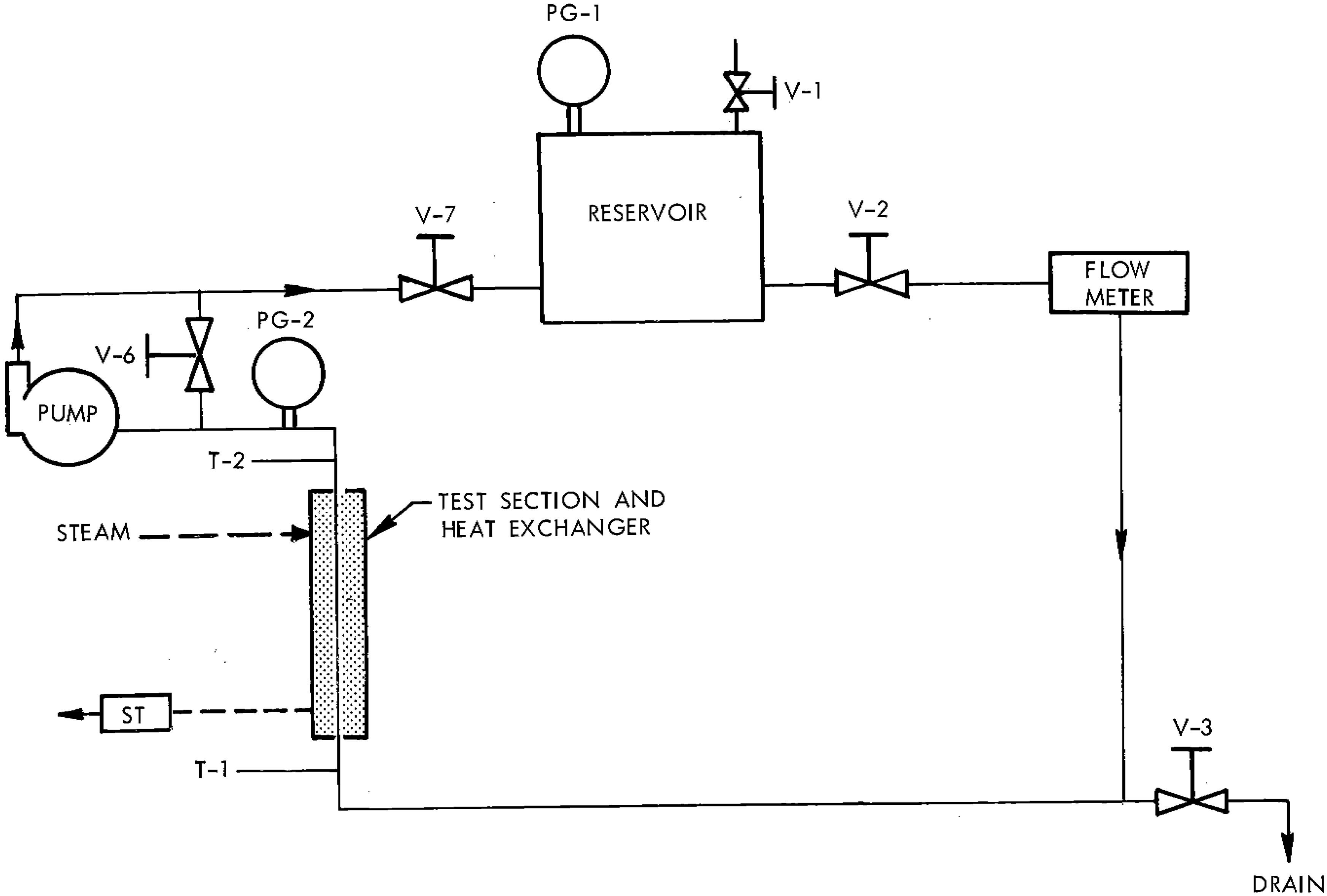



Figure 5 - Diagram of Brine Circulation and Scale Deposition System

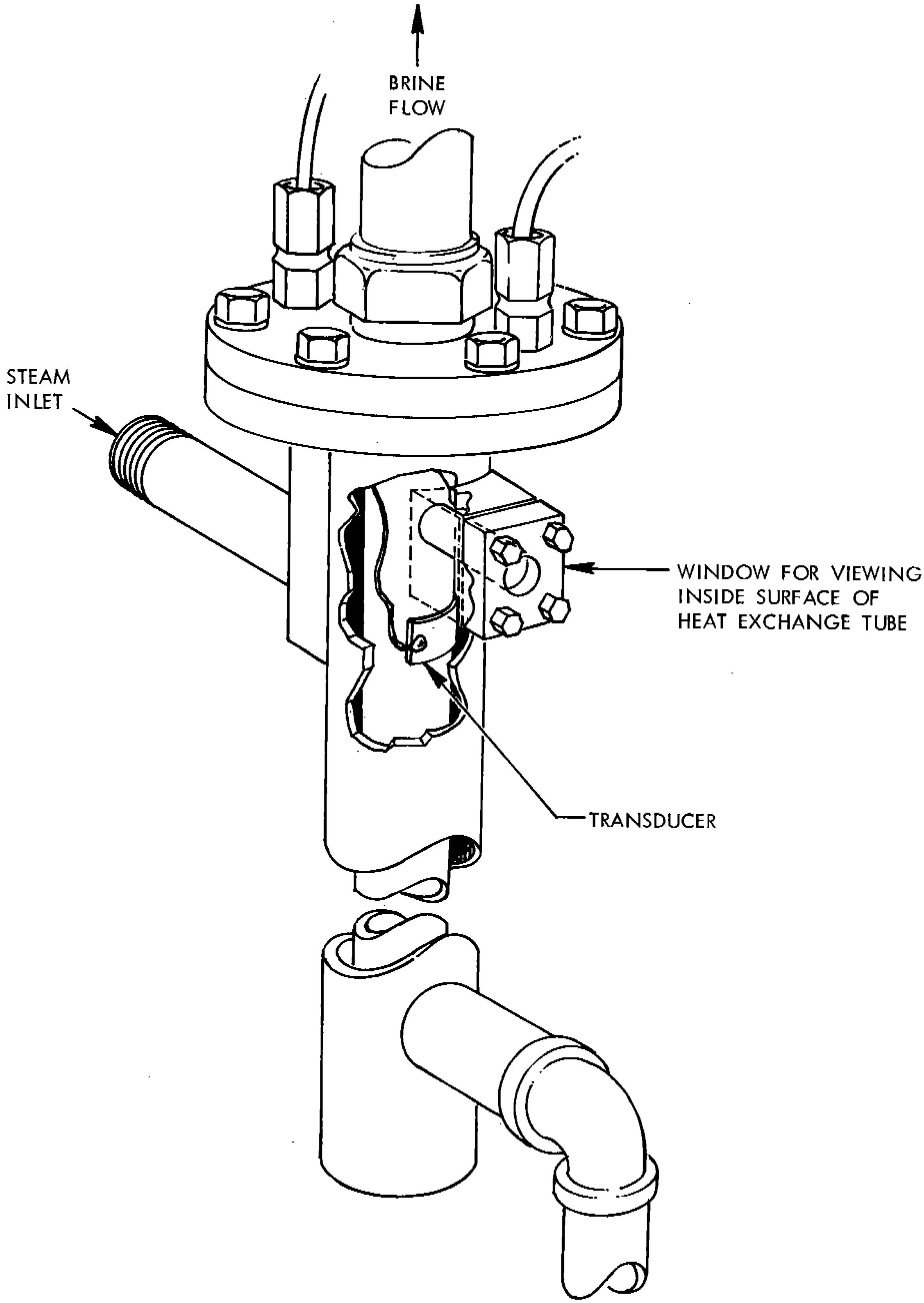
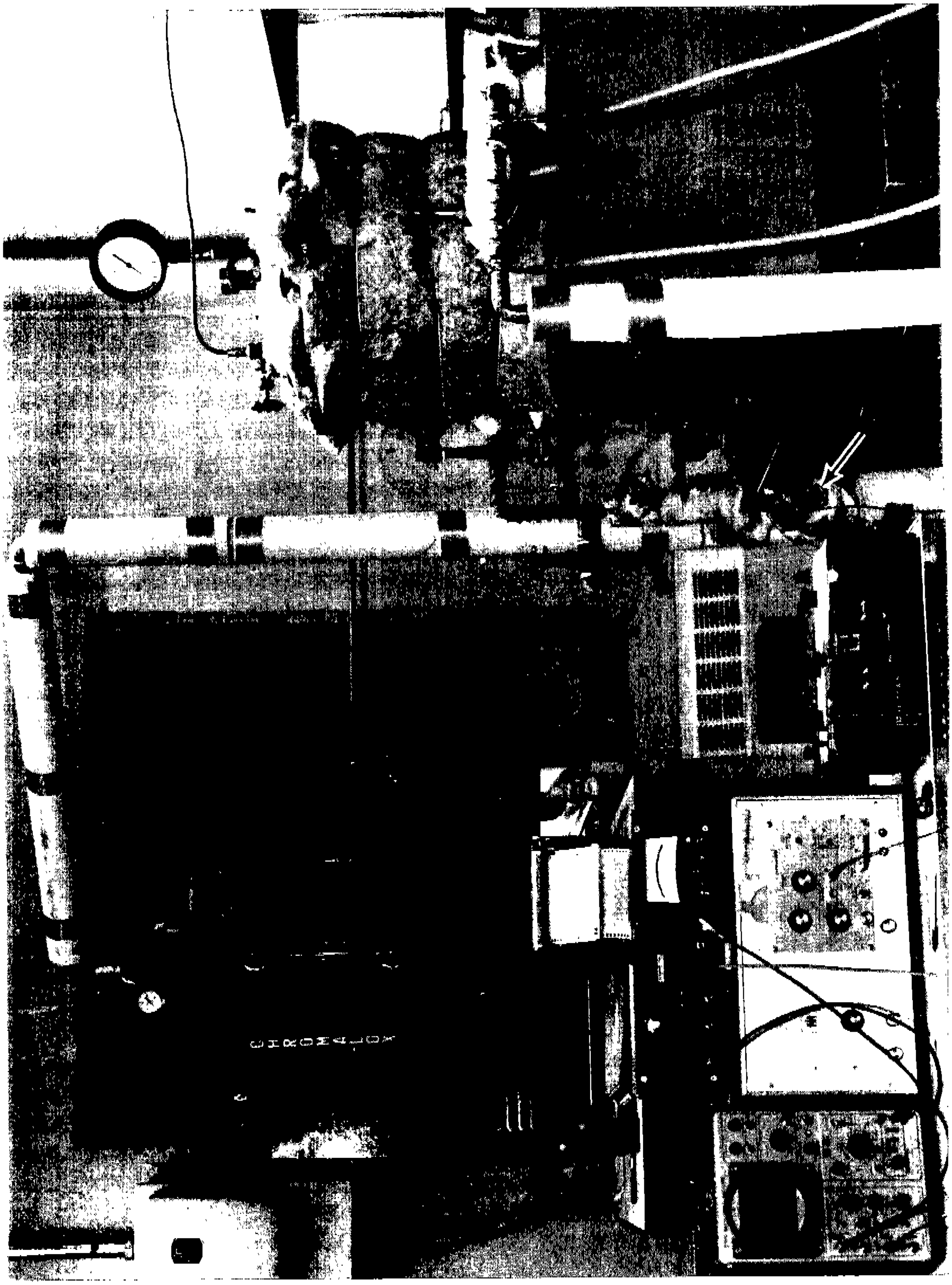



Figure 6 - Sketch of Test Section and Heat Exchanger



The Chromolox steam generator supplies steam for the test section heat exchanger. The small arrow identifies the optical port used for viewing scale deposits on the interior surface of the heat transfer tube.

The limitation on the upper temperature at which the above system can be operated is set primarily by the pressure which we feel the water reservoir can safely withstand. The reservoir is equipped with a pressure relief valve set at 50-55 psi so the water temperature is usually maintained below 146°C. Much higher steam temperatures are possible but 156°C was rarely exceeded during this program.

After the circulation and deposition system was assembled and checked out it was operated over a wide range of conditions in an effort to obtain different types of scale deposits. Test runs were completed using both simple calcium sulphate solutions and synthetic seawater at various concentration factors. Scale deposits were often successfully achieved but only in those cases where the brine or solution temperature was very close to, or in excess of, the solubility limit for $CaSO_4$ hemihydrate. In several test runs the system was operated for long periods at conditions approximately halfway between the anhydrate and hemihydrate solubility limits. Under these conditions we observed no indications of scale deposition. These results, together with observations of the scale deposits obtained when the hemihydrate solubility was exceeded, suggest that most of the deposit was hemihydrate.

## V. PROTOTYPE INSTRUMENTATION

Many of the early studies of ultrasonic changes induced by scale were completed with MRI equipment. A Matec Model 6000 RF pulse generator and receiver was used in conjunction with an oscilloscope to drive the transducer and evaluate the pulse-echo patterns. With this equipment it was concluded that sufficient sensitivity for scale detection could be achieved at an ultrasonic frequency of approximately 5 MHz. Higher frequencies are more strongly affected by scale but they are also subject to greater noise problems due to turbulence, cavitation, etc. With the frequency range established a search was initiated for commercially available equipment that met the following requirements: (1) light weight and compact, (2) operable in the desired frequency range, and (3) relatively inexpensive. After evaluating several instruments the Model USM2M produced by Krautkramer Ultrasonics, Inc., was selected as an acceptable unit. This unit does have the disadvantage of utilizing "spike" excitation but most of the available units, which satisfied other requirements, operate on a similar basis. The Krautkramer instrument is shown in Figure 8 along with one of the heat

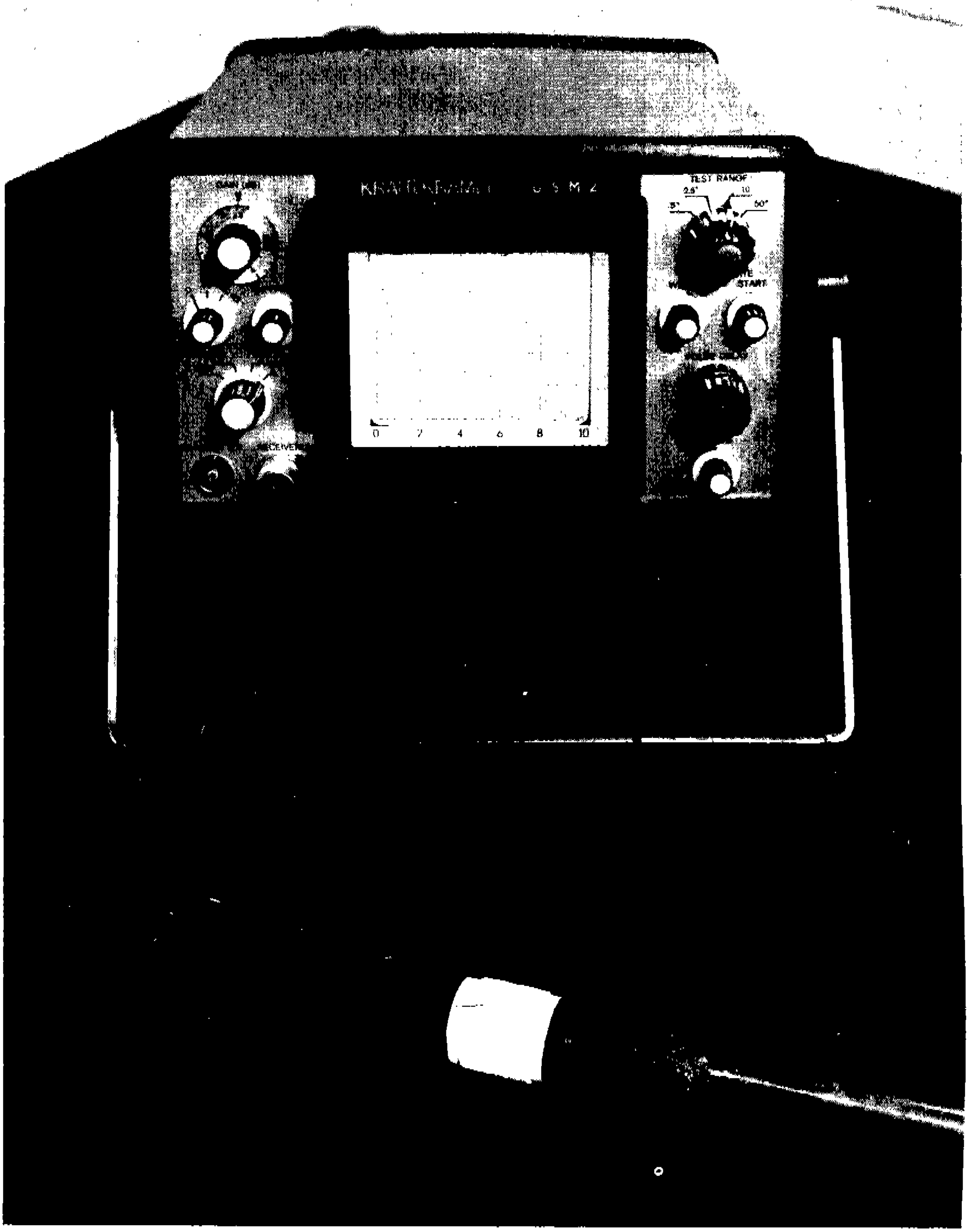


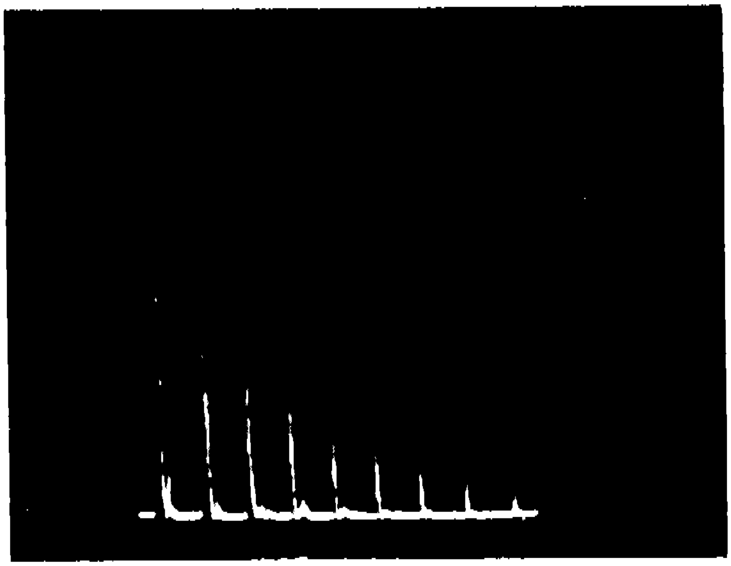

Figure 8 - Krautkrämer Model USM2M Ultrasonic Unit and Instrumented Test Section

transfer tube test sections. The equipment shown in Figure 8 includes everything necessary to ultrasonically evaluate scale conditions at one location in an operating plant. The test section, of course, must be used to replace a short length of ordinary tubing at the location where scale monitoring is desired. A simple multistation switch box can be added to facilitate periodic monitoring of several test sections with only one USM2M.

The USM2M is equipped with variable gain settings from 0 to 80 db., adjustable in 2 db. steps. This feature is utilized in making semiquantitative correlations between scale condition and attenuation of pulse-echo signals as observed on the cathode ray tube of the USM2M. Figure 9 shows two oscillograms taken from the USM2M with 5 gal/min flow through a 3/4 in. O.D. tube and a brine temperature of 138°C. The top oscillogram corresponds to a scale free condition while the bottom one is typical of deposits of several mils average thickness. The pulse-echo patterns shown in Figure 9 are not as clean looking as those previously shown in Figures 1b and 3b. The difference is primarily due to spike-versus-RF excitation. Nevertheless, the general character of the pulse-echo patterns is about the same for either form of excitation.

The gain control on the USM2M is used to evaluate attenuation in the following manner. The gain is adjusted until echo A has some convenient amplitude as identified by graticule lines on the CRT. The gain is then readjusted until echo B has the same amplitude. The difference in gain settings (expressed in decibels) represents the attenuation between echos A and B. We have found that the attenuation remains relatively constant over wide ranges of temperature and flow rates but varies significantly when scale deposits are present. A more detailed discussion of attenuation changes produced by scale is given in Section VI.

Another useful feature of the USM2M is a "gate monitor" which facilitates recording the amplitude variations of a selected echo. The width of the gate and its position in time can be varied by front panel controls. Figure 10 shows two oscillograms of the same pulse-echo pattern but the bottom oscillogram shows the monitor gate centered on the fourth echo. When the monitor is in operation a rear panel connector provides a DC voltage which is proportional to the amplitude of the echo within the gate. Thus, the DC output displayed on a strip chart recorder gives a permanent record of variations in the amplitude of the selected signal. We have found that such records are quite valuable in detecting early scale formation; however, it must be recognized that the amplitude of one echo is not as informative as the ratio of two echos. For example, the internal gain within the USM2M might decrease with time, due to deterioration of some electronic component, and the



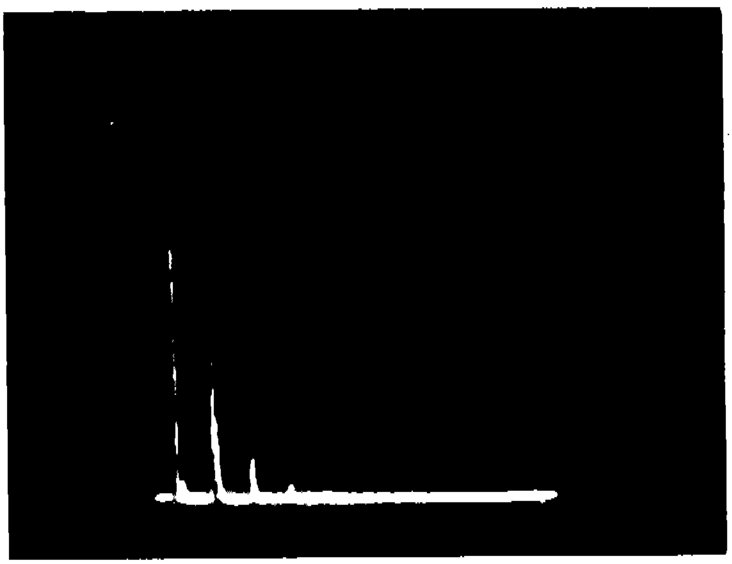


Figure 9 - USM2M Oscillograms Taken From Same Section of Tubing Before (top) and After (bottom) Scale Accumulation. Both oscillograms were recorded while synthetic seawater was flowing through the 3/4-in. O.D. tubing at a temperature of ~ 138°C. The flow rate was about 5 gal/min.

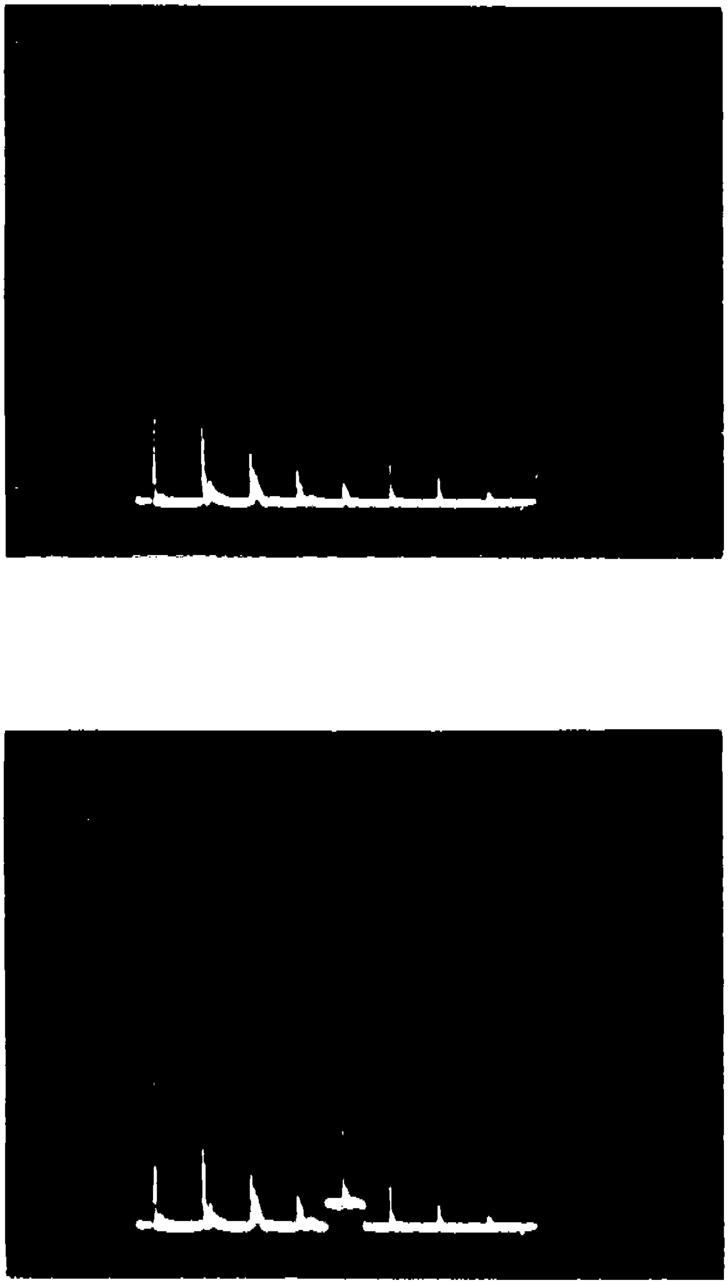


Figure 10 - Same Pulse-Echo Pattern Without and With Gate Monitor Set on Fourth Echo

amplitudes of all echos would thus decrease. However, the difference in amplitudes of two echos (expressed in decibels) would probably remain unchanged.

If the DC voltage is used to monitor an echo amplitude, a small integrating circuit can be placed between the USM2M and the recorder to smooth out rapid fluctuations that may be caused by occasional steam bubbles or other matter passing through the tube. The circuit shown in Figure 11 was used in our laboratory as an interface between the USM2M and a Hewlett-Packard Model 680 strip chart recorder. Since the output impedance from the USM2M monitor jack is relatively low and the input impedance of the recorder is relatively high, the components shown in Figure 11 largely control the time constant of the overall system. For the values shown, the time constant is approximately 7 sec.

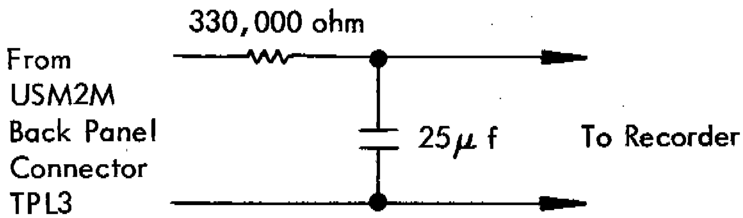



Figure 11 - Integrating Circuit for Smoothing Monitor Voltage Prior to Recording

When the gate monitor is in use a second connector on the rear panel provides an on-off voltage if the amplitude of the selected echo decreases below an adjustable level. If desired, this voltage can be used to actuate an audible alarm or a light at some remote location. This signal is useful in providing a warning of possible scale as well as undesired boiling within the heat transfer tube. The accumulation of scale, of course, causes a gradual and generally monotonic decrease in the echo amplitude. Boiling on the other hand produces wildly erratic changes in the echo return as steam bubbles form on the interior tube surfaces and become entrained in the fluid flowing past the transducer.

A minimum number of controls and adjustments exist on the USM2M and it is quite easy to operate. Detailed instructions on operation and maintenance are not presented in this report because the manufacturers manuals, which cover these subjects, will be delivered to OSW along with the test equipment. However, the following comments are pertinent to front panel controls as shown in Figure 12. The transmitter-receiver jacks are shown at lower left. In the unit to be delivered to OSW, the manufacturers special jack on the receiver side has been replaced with a more common BNC connector. The on-off and mode selector control is immediately above the transmit-receive connectors.

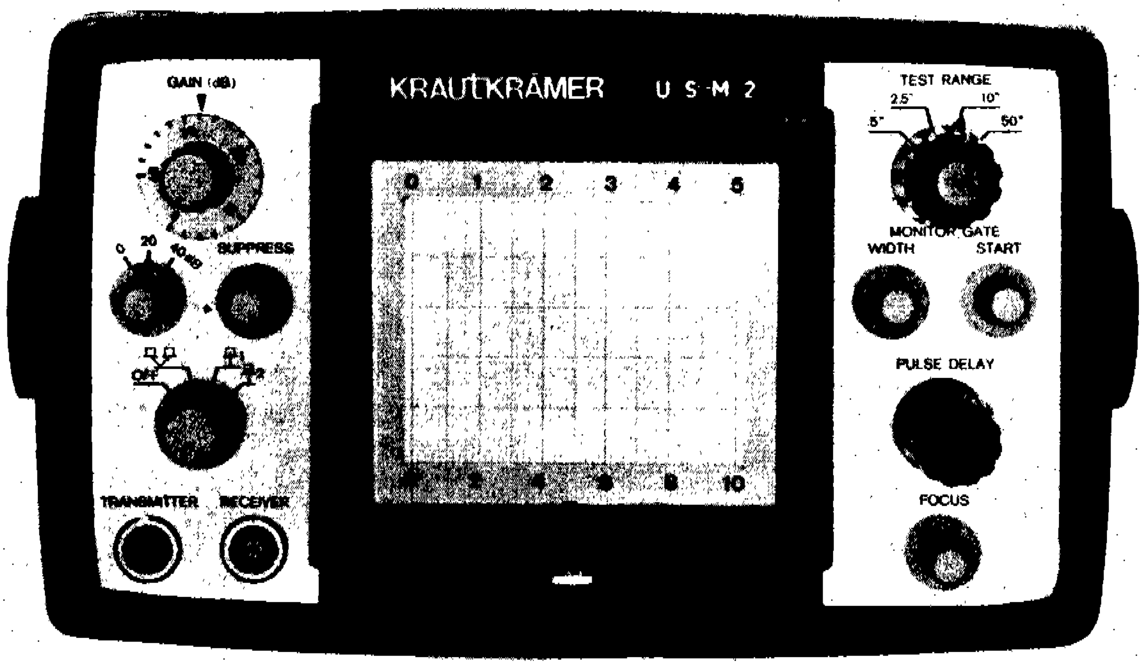



Figure 12 - Front Panel of USM2M Ultrasonic Unit

We recommend that the unit always be operated with this control in the most clockwise position (No. 2). In this position the transmitter and receiver sections are connected in parallel so that either connector can be used. We suggest use of the BNC connector mentioned above. The coarse- and fine-gain controls are above the on-off switch. The gain setting on the fine control is additive to that of the coarse control. Immediately to the right of the coarse gain adjustment is the "suppress" control. This control can be used to suppress low level noise with respect to larger signals but this is accomplished by making the CRT display nonlinear. It is suggested that this suppression circuit always be disabled by leaving the control in the most counterclockwise position. On the right side of the CRT, the topmost control is labeled "test range." This control affects the horizontal sweep rate of the CRT and is thus used to vary the number of echos displayed on the screen. Immediately below the test range control are two knobs which control the width and the starting time of the monitor gate. The pulse delay control allows one to delay initiation of the CRT sweep with respect to the time when the voltage spike is delivered to the transducer. The focus control performs the same function as the focus on any oscilloscope.

## VI. ULTRASONIC RESPONSE TO SCALE

During the course of this program, we concluded that it is impossible to make a highly accurate correlation between scale condition and changes in ultrasonic attenuation. This somewhat unfortunate fact is due to wide variations that exist in the general nature of calcium sulphate when deposited under different conditions of temperature, flow rate, concentration factor, etc. The deposits may vary in the percentage of different phases present, particle size distribution, and density. These properties are probably somewhat interrelated but they all affect the degree of ultrasonic scattering and absorption that occurs in the deposit. Of course, variations in the above properties also result in different heat transfer characteristics. In fact, it is very likely that heat transfer and ultrasonic attenuation are both affected by scale variations. For example, a low density scale deposit will probably result in a somewhat greater ultrasonic attenuation and a lower heat transfer efficiency than a denser deposit of the same thickness.

Wide variations in scale characteristics were observed as deposition occurred at different temperatures, flow rates, etc. Scale conditions were often photographed through the viewing port (see Section IV) and studied relative to the resultant effect on ultrasonic signals. As mentioned previously, most deposits appeared to be predominantly hemihydrate. Enlarged photographs of two typical deposits are shown in Figures 13 and 14. Although there is still much of the bare tube surface visible in Figure 13, this deposit produced a significant increase in the ultrasonic attenuation. The deposit of Figure 14 produced an even stronger effect.

Despite the variations discussed above it is possible to semi-quantitatively relate changes in ultrasonic attenuation to the presence of scale. Under ideal conditions, it is quite easy to detect deposits with an average thickness of well under 0.001 in. However, using the test sections of tubing supplied under this contract and the USM2M electronic equipment, we believe that the lower range of reliable detection should be considered as a thickness of about 0.001 in. A scale deposit of this thickness produces a change in attenuation between the second and fifth echo of about 2 db., which is significantly larger than that produced by wide variations in temperature or concentration factor.

Table I identifies the standard test sections by number and dimensions, and gives the approximate attenuation between the second and fifth echos when no scale is present. The attenuation values should be considered as an approximate reference for each section.

TABLE I

CHARACTERISTICS OF TEST SECTIONS OF TUBING

| Identification Number | Outside Diameter (in.) | Wall Thickness (in.) | Attenuation Between Second and Fifth Echo (db.) |
|---|---|---|---|
| 1 | 1 | 0.049 | 10 |
| 2 | 3/4 | 0.035 | 8 |
| 3 | 3/4 | 0.035 | 11 |
| 4 | 3/4 | 0.035 | 10 |
| 5 | 1 | 0.030 | 12 |

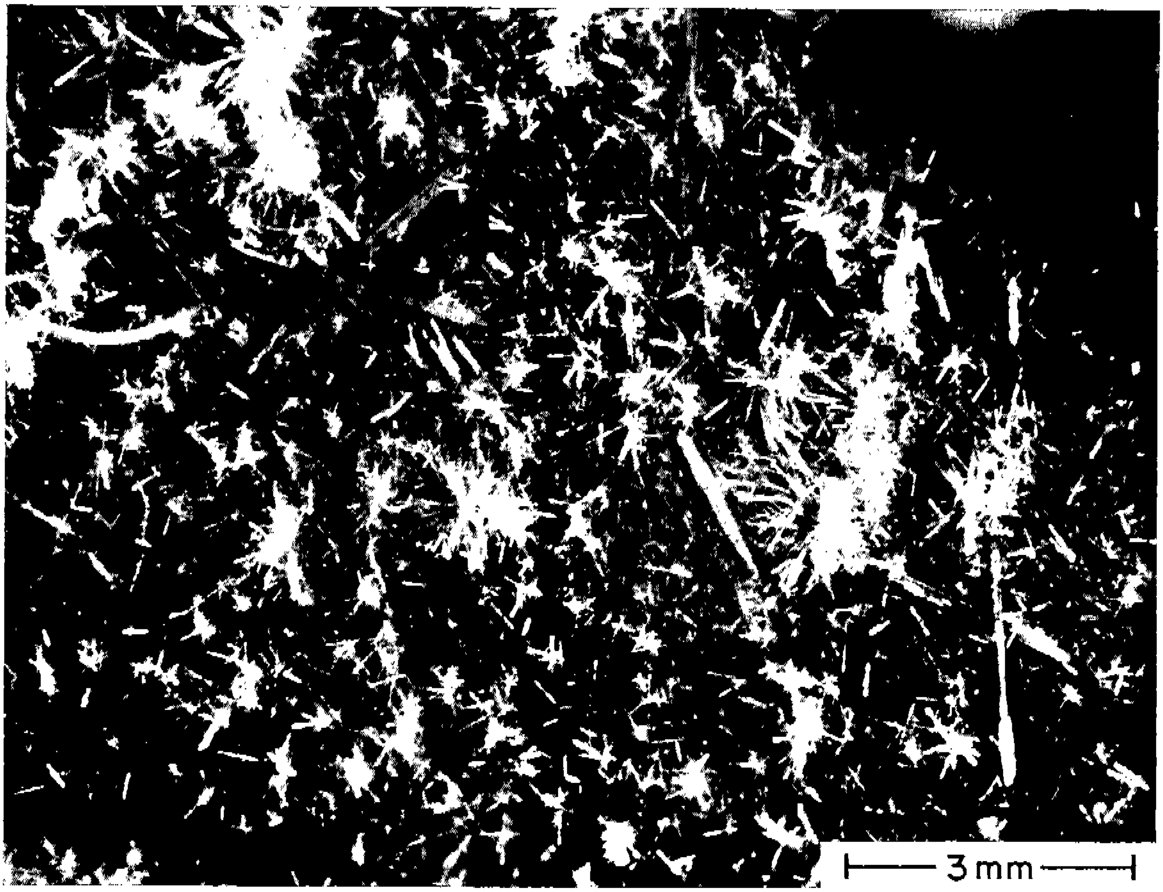



Figure 13 - Scale Deposit Containing Preponderance of Fine Hemihydrate Needles


Figure 14 - Deposit With Heavier Hemihydrate Needles and Perhaps Some Anhydrate

Thus, a scale deposit of about 0.001-in. thickness should cause the attenuation between the second and fifth echo for tube No. 1 to change from 10 db. to 12 db., while for tube No. 2 the change will be from 8 db. to 10 db. The increase in attenuation is roughly proportional to scale thickness. Thus, a 0.002 mil deposit should produce a 4 db. increase in attenuation above the reference value.

In many of the laboratory tests, the gate monitor was used to provide a permanent record of changes in the third echo amplitude while only intermittent measurements were made in the attenuation between the second and fifth echos. Figure 15 is a recording trace from one test run with the attenuation readings superimposed. This particular set of data was taken with test section No. 2. The brine temperature was rising slowly from about 130 to 140°C during the period of the test. The flow rate was constant at 5 gal/min. The attenuation readings remained constant at 8 db. while the recorder trace, representing the third echo amplitude, was practically invariant. Then as scale began to deposit the third echo amplitude decreased and the attenuation increased.

Test sections Nos. 1-4 were all made of commercial cupro nickel tubing with standard wall thicknesses. If these test sections are used to replace similar tubing in flash distillation plants, the scale deposition within the test section should be representative of that in surrounding tubes. Because of the thermal insulation provided by the transducer and the surrounding silicone sealant there will be a reduction in the scale thickness immediately beneath the transducer. However the opposite side of the tubing is unaffected and the scale there will be "typical" of normal tubes in the same environment. Test section No. 5 was made from tubing with an original wall thickness of 0.049 in., but the wall thickness was reduced to 0.030 in. by reaming. If this section is substituted for tubing with 0.035 in. wall thickness, scale will grow faster in the test section than in the surrounding tubes because of the greater heat flux transferred by the thinner wall. The effect will be even more pronounced if the section is substituted for tubing with 0.049 in. wall. In either case the result will be heavier scale in the test section and a resultant increase in sensitivity for detection of very light deposits.

Figures 15 through 17 show USM2M oscillograms representative of the pulse-echo patterns for each test section listed in Table I. The gain setting at which each oscillogram was taken is also given.

All of the test sections exhibit pulse echo patterns that are reasonably exponential and the attenuation between the second and fifth echos does not vary too greatly.

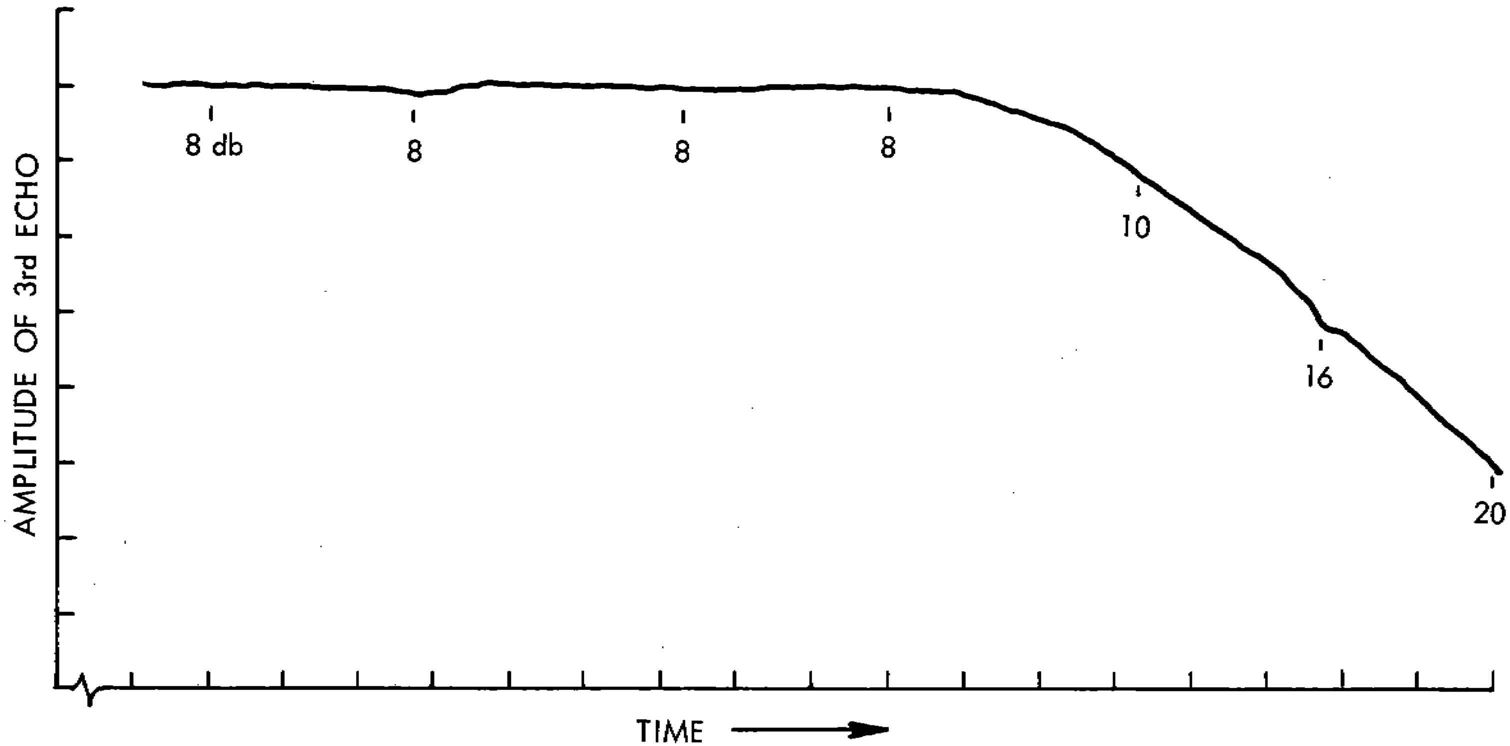
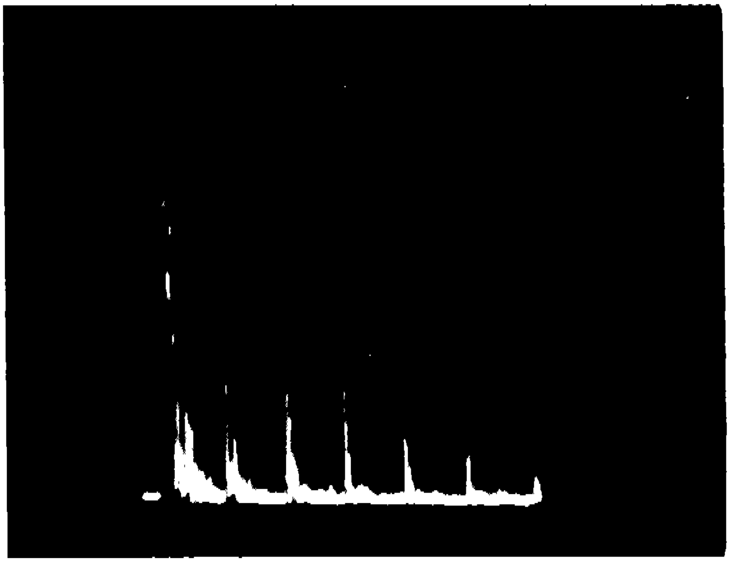
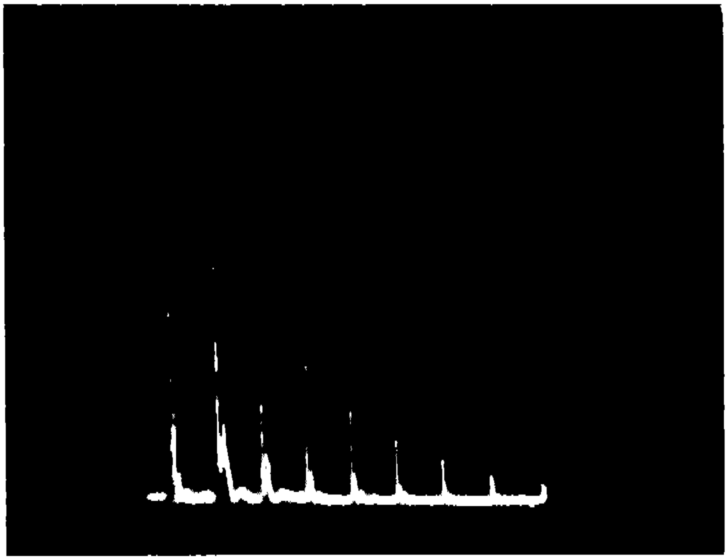



Figure 15 - Variation in Amplitude of Third Echo During Deposition Run on Test Section No. 2. Numerical values indicate attenuation between second and fifth echos.

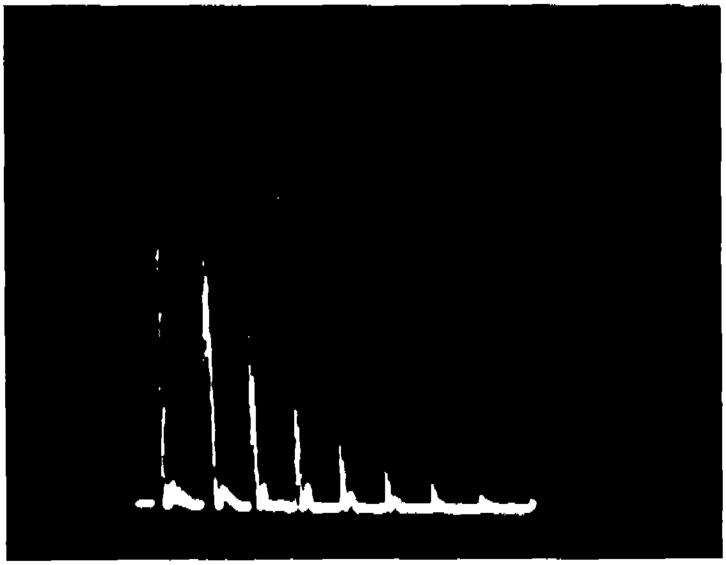


Test Section No. 1
Gain = 46 db.

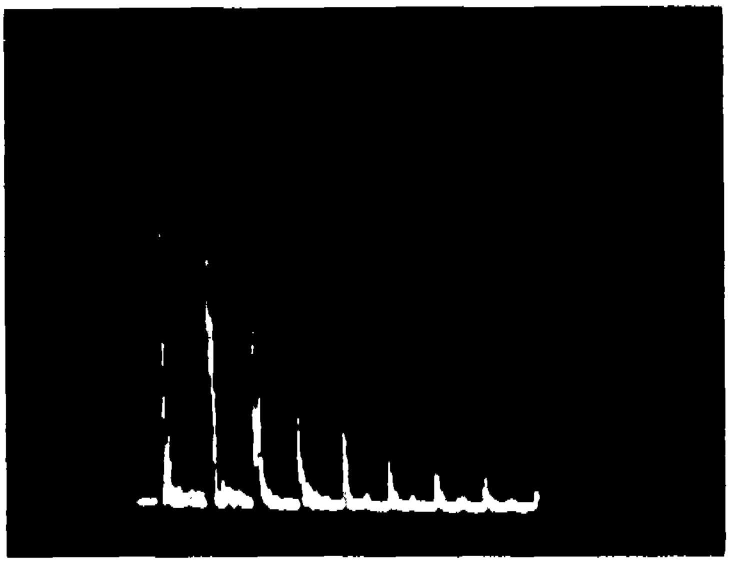


Test Section No. 2
Gain = 20 db.

Figure 16 - Oscillograms From Test Sections No. 1 and No. 2



Test Section No. 3
Gain = 14 db.



Test Section No. 4
Gain = 20 db.

Figure 17 - Oscillograms From Test Sections No. 3 and No. 4

However, as seen in Figures 16-18, a wide range of gain settings are required to obtain patterns of approximately the same amplitude. These variations are apparently due to differences in the quality of the solder bond. Before a test section is installed in an application area, it should be filled with water and connected to the USM2M. A CRT trace resembling the appropriate oscillogram in Figures 16-18 should be obtained or the test section should be considered suspect of transducer damage.

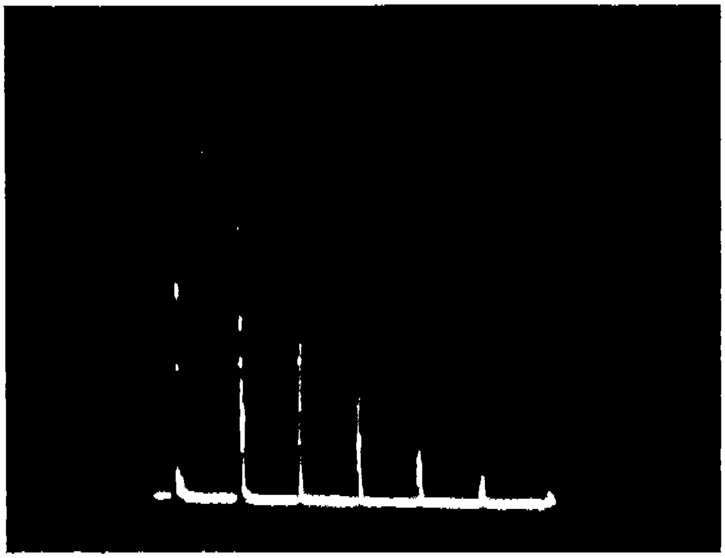


Figure 18 - Oscillogram From Test Section No. 5
Gain = 10 db.

## VII. CONCLUSIONS

1. Ultrasonic pulse-echo reflection techniques can be used on heat transfer tubing in flash distillation plants as a means of detecting scale deposits with an average thickness of approximately 0.001 in.

2. Because of eccentricity of some commercial tubing, it is difficult to always obtain reproducible pulse-echo patterns.

3. A number of test sections have been fabricated from specially selected tubing and affixed with transducers which provide reasonably good exponential pulse-echo patterns. These test sections can be substituted for normal tubing at locations where initial scaling is expected.

4. The electronic equipment supplied with the test sections is simple to operate and compact in size.

5. The ultrasonic pulse-echo patterns are also sensitive indicators of undesired boiling.

6. By using test sections which have a wall thickness less than that of the surrounding tubing one can insure preferential scale deposition in the test section and thus increase the sensitivity for detection of very light deposits.



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